Experimental report

07/09/2018

Proposal: **CRG-2439** **Council:** 4/2017

Title: Time-resolved study of the multiferroic domain inversion in $NaFeGe_2O_6$

Research area: Physics

This proposal is a new proposal

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Samples: $NaFeGe_2O_6$

Instrument	Requested days	Allocated days	From	To
IN12	6	5	04/04/2018	09/04/2018

Abstract:

The control of magnetic domains by electric fields stimulates the large interest in multiferroics as data-storage media. We have studied the rise-times to switch the chiral magnetism in several compounds. $MnWO_4$ and $Ni_3V_2O_8$ exhibit increasing rise times upon cooling only close to the multiferroic transition; in contrast $TbMnO_3$ shows an unexpectedly simple activation law followed over ~5 decades in time. In order to explain these differences we propose to study another multiferroic material, $NaFeGe_2O_6$, which exhibits a qualitatively different phase diagram.

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The main goal of the allocated beamtime was to investigate the multiferroic domain inversion times as a function of temperature and electric field on single crystals of $NaFeGe_2O_6$. For corresponding time-resolved measurements 5 days of beam-time on IN12 have been allocated. The instrument has been operated in the full-polarized mode and we used our own high-voltage setup for a time-resolved data collection. Two samples that had been oriented in the scattering planes (1 0 0)/(0 0 1) and (1 0 0)/(0 1 0) respectively have been used for measurements during the experimental course. $NaFeGe_2O_6$ possesses two reported magnetic phase transitions at $T = 13\,\mathrm{K}$ and $T = 11.6\,\mathrm{K}$, whereat below the latter transition the system shows multiferroic behavior [1–4]. Within this multiferroic phase, the magnetic moments are reported to form a helix confined within the ac-plane [1,2]. A slightly temperature dependent incommensurate propagation vector $\mathbf{k} = (0.32\ 1\ 0.08)$ has been documented for both magnetic phases [1].
First, in order to find the position of maximum intensity for the magnetic reflections, we screened a temperature dependent shift of the k_x and k_z values of the propagation vector by executing Q_H and Q_L scans as a function of temperature. The corresponding collection of data has been done for different polarization directions and by measuring spin-flip and non spin-flip channels. From these data sets, it was also possible to conclude in which direction the spins are pointing below the first and second magnetic phase transition. From previous reported studies, it was unclear, whether a small b-component is present in the multiferroic phase or not [1]. The lack of this component in the multiferroic phase disagrees with the reported small b-component of the macroscopic electric polarization $\mathbf{P}$ [4], when considering the relation $\mathbf{P} \propto \mathbf{e_{ij}} \left(\mathbf{S_i} \times \mathbf{S_j}\right)$ with $\mathbf{e_{ij}}$ being the connection vector between the two neighboring spins $\mathbf{S_i}$ and $\mathbf{S_j}$.

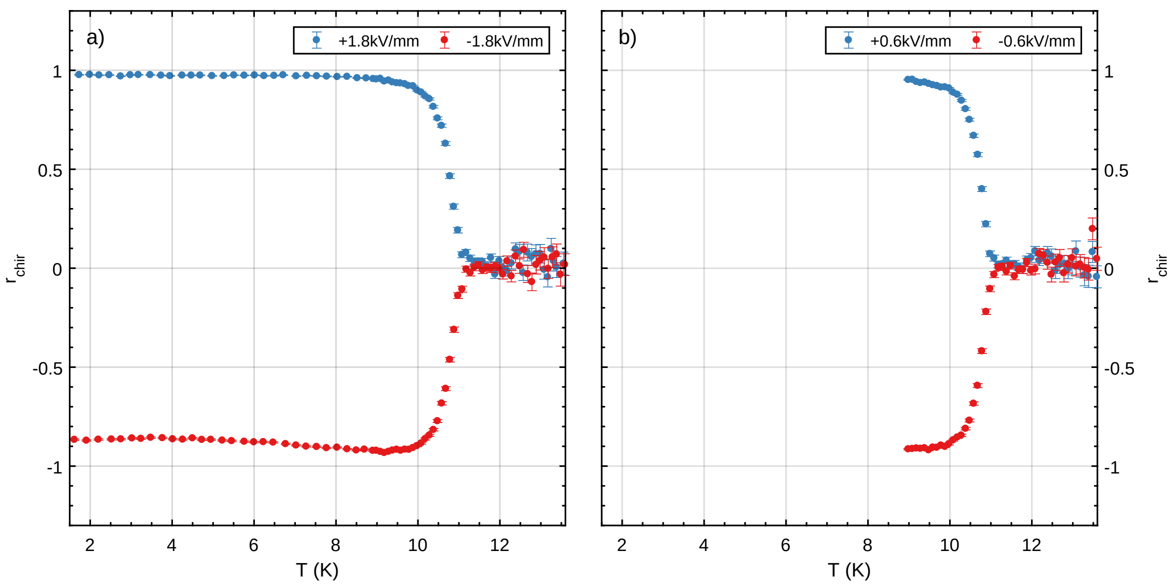

Figure 1.1: Poled chirality for different field amplitudes
The data has been recorded by applying a constant electric field above the phase transition and subsequent cooling in the field. Both data sets in a) and b) have been measured on the magnetic $\mathbf{Q} = (0.32\ 3\ 0.08)$ reflection.

Our polarized diffraction measurements clearly evidenced the presence of a b-component within the multiferroic phase and hence the well known model from Dzyaloshinskii-Moriya [5,6] is still applicable to describe the direction of the electric polarization. After these initial studies, we applied a constant electric field to the sample, while cooling the system below the multierroic phase transition. For applying an electric field to the system, the sample has been squeezed between to aluminium plates, which are only connected by insulating teflon screws. Measuring the two spin-flip channels $I_{x\bar{x}}$ and $I_{\bar{x}x}$ gives access to the chiral ratio r_{chir}.

$$r_{\mathrm{chir}} = \frac{I_{x\bar{x}} - I_{\bar{x}x}}{I_{x\bar{x}} + I_{\bar{x}x}} = \frac{-i\left(\mathbf{M}_{\perp} \times \mathbf{M}_{\perp}^{*}\right)_{x}}{|\mathbf{M}_{\perp}|^{2}} \tag{1.1}$$

It has to be noted that a right handed coordinate system with $-x||\mathbf{Q}$ has been used. In order to sense the chirality of the system, the magnetic Bragg peak $\mathbf{Q} = (0.32\ 3\ 0.08)$ has been measured. Due to the scattering geometry, the chosen $\mathbf{Q}$-vector is almost perpendicular to the cycloidal plane and hence, chiral ratios of ± 1 are expected for monodomain states. The recorded data is displayed in figure 1.1 and it can be seen that for both field strengths, the handedness of the spin spiral can be completely poled to a monodomain state. Additionally the handedness can be poled in the opposite direction by applying a reversed electric field to the sample. During the subsequent measurements, the electric field has been driven continuously between its both polarities in order to record hysteresis cycles of the chiral ratio. Corresponding plots are shown in figure 1.2

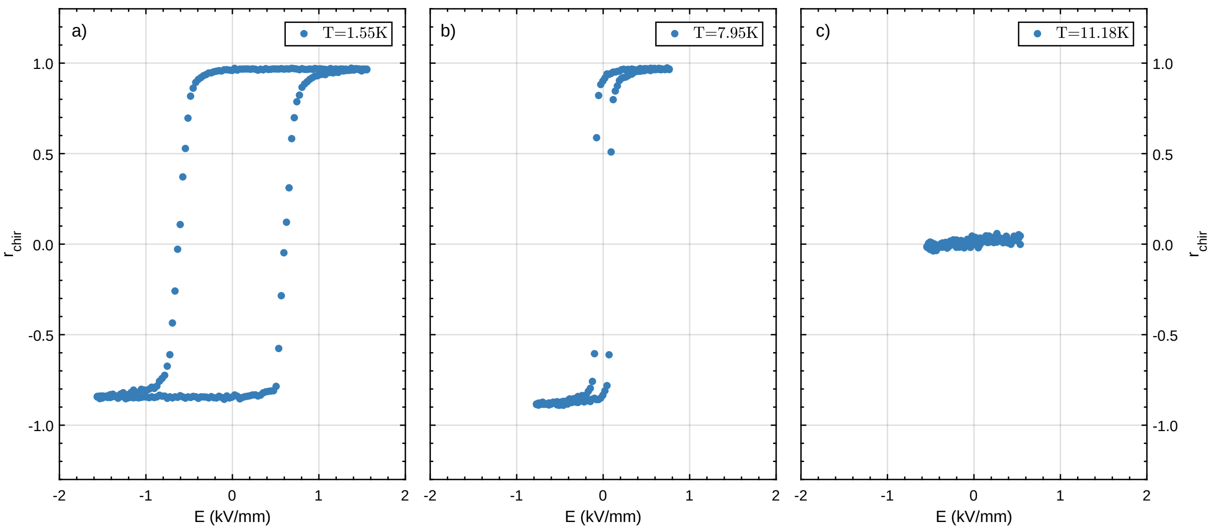

Figure 1.2: Temperature dependent hysteresis cycles
The shown hysteresis curves are exemplary for the recorded cycles at different temperatures. As expected, only below the multiferroic phase transition, these curves are detectable.

It can be seen that hysteresis curves are detectable below the multiferroic phase transition and for the given field amplitude, the chiral ration can be fully reversed down to the lowest temperature $T = 1.55\,\mathrm{K}$. During the last days, time resolved switching curves of the chiral ratio have been recorded. These curves have been measured for different temperatures and also for different electric field amplitudes. Two exemplary switching curves are plotted in figure 1.3. It can be seen that for lower temperatures the domain inversion time increases by several orders of magnitude. The analysis of all recorded temperature and electric field dependent curves will answer the question, whether one can follow the rise times of $NaFeGe_2O_6$ also by a simple activation law as in the case for $TbMnO_3$ (report CRG-1971) and $Ni_3V_2O_8$ (report CRG-2290).

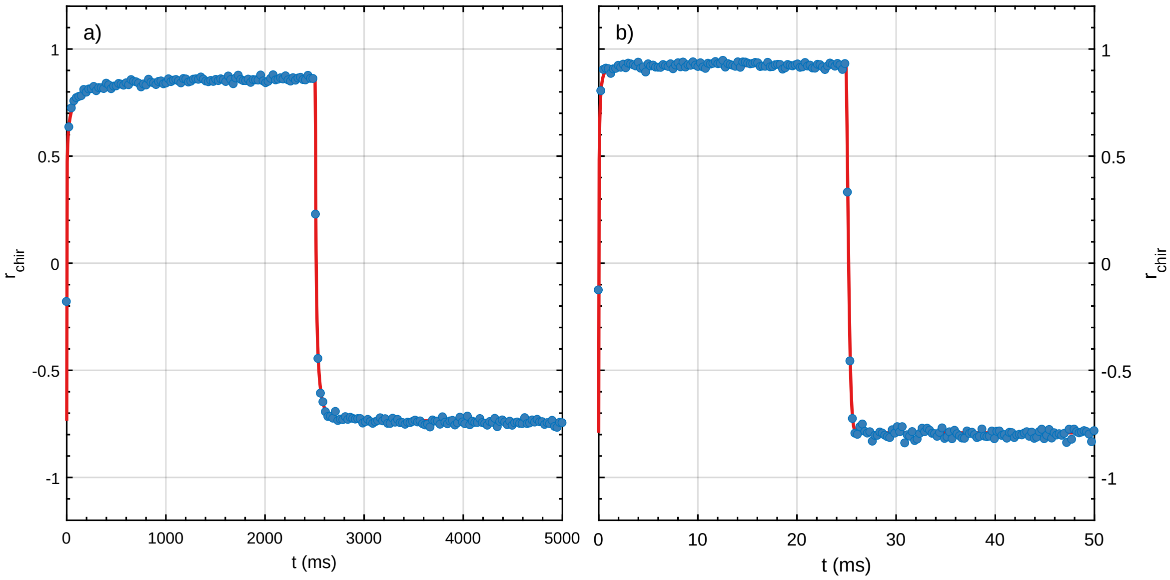

Figure 1.3: Time resolved domain inversion
Both figures a) and b) display switching curves for an applied field amplitude of $E = 420\,\mathrm{V\,mm^{-1}}$ at $T = 3.5\,\mathrm{K}$ and $T = 5.5\,\mathrm{K}$ respectively.

We would like to acknowledge for the allocation of this beamtime and the excellent on-site support from our local contact Wolfgang Schmidt and all technicians. The large amount of recorded data helps to further push on our research in this field and to understand the microscopic mechanism of multiferroic domain inversion.

References

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